NUMBER 34
OCCASIONAL PAPERS
ENGINEER SCHOOL
UNITED STATES ARMY

On the Amelioration of Rivers With Unstable Beds by the System Audouin

Translated from the French at the Engineer School, 1908

WASHINGTON BARRACKS, D. C.
PRESS OF THE ENGINEER SCHOOL
1908

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ON THE AMELIORATION

OF

Rivers With Scourable Bottoms and Especially of the Loire

Extract from Nouvelles Annales de la Construction
April, 1904

FOLLOWED BY A

PROJECT FOR A TRIAL

OF THE

Oblique Dams With Suspended Movable Vanes

(System Audouin)

BY

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On the Amelioration of Rivers With Scourable Bottoms and Especially of the Loire.

OBLIQUE DAM.

Let us see how these conditions can be satisfied. Let us consider a sinuous part of the Loire, and let us suppose that the banks have been rectified as explained above. The portions AB, CD are regular curves, and there is produced naturally deep hollows from *a* to *b* and from *c* to *d*. The question is to connect these two pools through the sill in order to have a continuous channel. Let us place at BE an oblique resisting wall; its obliquity will create a locus of excavation. But at the same time it reduces the section of flow and the velocity will increase. This action will be added to the first; scour will be produced along BE, increasing with the angle of the dam and its length. It is always possible to chose the angle and length of this dam in such manner as to obtain the necessary scour in the time desired.

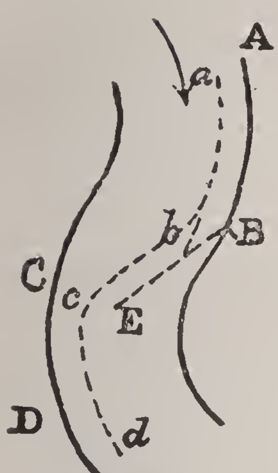

Fig. 1.

DAM WITH SUSPENDED VANES.

Let us see now how this scour is made and what will become of the sand transported.

It is known that sand transported by the current is carried for the most part on the bottom of the river. Particles of earth put in suspension remain in greater proportions in the lower layer than in those nearer the surface. (Report of M. Guérard, ingénieur en chef at Marseille, to the Congress of Interior Navigation at Paris, 1892.) Hence if, in place of making the wall BE by a dam resting on the bottom, it is constructed of vanes maintained at a short distance therefrom, there will be created under the dam a strong current, which will produce a rapid scour, carrying the sand *behind the dam;* if this bottom current is reduced sufficiently in thickness in relation to the total depth of the water, the velocity will be very quickly reduced behind the dam and the sand will be deposited. We will be able at will to produce this deposit at a greater or less distance by

augmenting or diminishing the height of the opening left to the current under the vanes.

As to the phenomenon of the concentration of quantity of movement, created by the oblique dam, this will be felt over a zone more or less broad along the dam; there will result a scour of the bottom and the sand placed in movement, rolling along on this bottom, will fall into the deep trough scoured under the dam and will pass in its turn behind this latter.

The greater part of the sand transported will be deposited behind the dam and will form a bar exactly in front of the convex bank, which is its natural place, whence the current will not tend to dislodge it even in floods, when the vanes are raised; for the dam has been placed precisely at the point where the natural force of scour of the current ceases to be sufficient of itself.

A very small quantity of sand will be carried parallel to the dam; it will be deposited downstream of the latter in zone encountered outside the current, and but a very small quantity will fall into the pool *cd*, which will not be sensibly modified.

All these phenomena have been verified by an experiment (though imperfect) made in the Loire in July, 1897, when the waters reached a stage of only 0.80 m. above low water. The scour produced by the current passing under vanes slightly raised reached rapidly in a few days a depth of about 1 meter. As to the zone in which the concentration of quantity of movement was noticeable, it embraced a width of 30 to 40 meters and the transverse profile possessed a regularity similar to that of an artificial canal.

By operating at average stages—that is to say, at 2 meters above low water—the scour would have greater depth; the breadth of the excavated zone would be somewhat augmented.

It is important to remark that this scoured zone is relatively narrow, and this is fortunate, because, thus, the sill (crossover) is completely levelled down; it is simply crossed by narrow and deep channel, analogous to the dredged channels projected by M. Pasqueau for the banks on the Garonne. These furrows modify very little the wetted section of the river at low water, and, consequently, they have the advantage of giving the greater depth of channel without lowering the plane of low water above.

Thus, when the natural banks of a river present a trace approaching the normal trace indicated by M. Fargue, we will be able, by simple inexpensive works, to give to the concave banks regular and progressive curves. There will then be obtained a continuous channel, always navigable, by rectifying the concave banks and placing *temporarily* near the points of

inflection an oblique movable dam with suspended vanes capable of regulation.

This design will have over those now in use the advantage of not provoking the permanent lowering of the crossovers; it will excavate only a narrow and deep furrow, modifying but little the wetted section; in consequence, no trouble will be caused upstream while giving at the place of improvement a draft of water sufficient for all the needs of navigation.

It also has the advantage of being more economical than other methods, and, in case of floods, forms no obstacle to the free flow of the waters, for it is seen, without other explanation, that the vanes can be rapidly taken out in such case and there will remain only the piles which support them and which will offer but little interference to the floods.

We will add, also, that the inventor has foreseen the case where it may be desirable to leave nothing permanent in the bed of the stream and that he has studied a special arrangement to sustain the vanes by floating supports, which can be transported from point to point in the stream.

We will not enlarge on the case of a river presenting several arms or branches where one of them only is to be improved.

It is important to remark that the works of correction of the banks, of which we have spoken above, are applied to the natural banks of the river; when it becomes necessary to substitute artificial works these should be raised to the average height of the banks—that is to say, 3 meters or 3.50 meters above low water. This is an essential condition to obtain the scour desired; for it is only during average stages that the channel can be regulated in a permanent manner. M. Jacquet, inspector-general of Ponts et Chaussées, has shown in a report to the International Congress of utilization of river waters in 1889:

"The action that the waters exert on the bed depends on the discharge, and, for each discharge, on its duration. Floods and low waters are not those which give to the bars or, more generally speaking, to the bed of the stream, the forms of relief seen at low water. The effect produced by great floods is modified by the less high waters that follow and which determine the definitive form that persists after each flood. These intermediate stages, above low water, are really regulators of the low-water bed, and it is on them that we must base our study of the limit of action on the created minor bed."

Low works too long submerged are, moreover, proscribed in the scheme before us.

As soon as an oblique wall is submerged it ceases to be a strong cause

of scour. This fact has been observed very clearly on the Loire in 1897, notably above Ingrandes.

RESUME.

To sum up, the design of M. Audouin for the amelioration of rivers with erodible bottom consists essentially in the rectification of the banks of the mean bed, completed at need by plunging spurs joined to the convex shore, a permanent amelioration which is only partial and insufficient in low waters, and to complete this amelioration by the creation of an artificial channel through the crossings, but only during low water.

The means proposed to create this furrow constitutes in itself an innovation of general interest. It may be found of advantage for the improvement of rivers emptying into tideless seas. The sort of decantation and storing of the sedimentary matter that it can cause all along the course of an important river of this nature would have for subsidiary effect to retard in certain measure the advance of the delta by diminishing the supplies which go to form it.

This is a new and very simple idea, of which the importance will escape no one.

Project for Oblique Dams With Suspended Movable Vanes.

(System Audouin.)

The project that is presented here has for its aim to demonstrate the practical working of dams with suspended vanes (system Audouin) for the improvement of rivers with erodible bottoms.

All engineers known the difficulties presented by this problem. For years the trials of all sorts that have been made to solve this problem have been almost sterile, and it may be said that it is only since the researches and works of Inspector-General Fargue that we are able to determine the conditions under which improvements ought to be attempted and that we have been able to carry them out effectively. The examples of the Rhone and the great German rivers show what success may be expected.

However, certain rivers present very exceptional difficulties. Among these particularly is the Loire. Here is found a major bed limited by dikes, that must be made insubmersible, between which ought to be theoretically contained the waters of the great floods, and which must not be overflowed or broken under penalty of great disasters in the neighboring low lands they are designed to protect.

The establishment in the bed thus constituted of permanent works which would concentrate the waters in a determined bed beforehand can not be considered; for they would, as a consequence, diminish the section of flow, already scarcely sufficient during extremely high floods. On the other hand, during the period of low water, the discharge is reduced so much that navigation becomes impossible if all the discharge can not be confined in a minor bed sufficiently restricted in order that this small quantity of water may nevertheless assure the passage of the boats which frequent the river and render their passage of the crossings possible.

It results from these numerous conditions that the solutions adopted elsewhere and which have given satisfactory results meet here difficulties of a quite special order and that it is practically impossible to predict whether or not their use would be crowned with success.

The system designed by the late Captain Audouin, of which a practical trial is now proposed, would appear to prove efficacious where these other methods could succeed only with great difficulty or imperfectly. The principles on which it rests are, in sum, only happy and reasonable appli-

cations of those which M. Fargue has formulated. We will not develop them here and will refer for their exposition to the brochure in which they are clearly described.* But before speaking of their application, it will be well to develop some general considerations, attaching more especially to the Loire.

When one looks over the successive plans of soundings of this river executed at different epochs and with the greatest care by the engineers of the Special Service of the Loire, one can not fail to recognize, among the incessant secondary changes that the waters impress on the form of the bottom, certain characteristics which appear to remain constant or which vary within small limits. It may be stated, in passing, that the laws of M. Fargue find here their verification. The pools or hollows are found along the concave banks, the bars are at the crossovers between two pools—that is to say, at the points of inflection which separate two consecutive curves, concave in opposite sense. The bed of the river is then formed of a series of echelons of which the pools and the crossings constitute the steps.

In order to ensure navigability at low water, it is then necessary to render possible the passage from one pool to the next; but it must be done with the condition that the stage of the upstream pool is not sensibly changed by the works executed. Without this, the improvement of the difficult passage will have, as a consequence, to aggravate the condition of the region upstream and therefore render more difficult the works needed there. The difficulty is only moved from one locality to another.

If the discharge at low water were always sufficiently great, it might be possible, by uniting and concentrating all the water, to diminish to a certain extent these undesirable effects without, however, escaping them altogether. But as this is not the case on the Loire, it follows logically that the crossings to improve must, naturally, present the depth necessary for navigation and have sufficient breadth to assure at all times the easy passage of boats, but that it would be imprudent, and even be inimical to the end in view, to try to obtain at these points channels of greater breadth than is strictly necessary, for the normal low water will not be sufficient to fill them and consequently no local improvement will be realized, while having, moreover, aggravated the general condition.

From what precedes, the end to be attained is then to form, from one pool to the next, channels of breadth and depth strictly sufficient to these desiderata by means of works that do not obstruct the bed of the river when in flood.

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*Esquisse d'un nouveau système d'amélioration des rivières à fond mobile, par L. Audouin, capitaine d'artillerie breveté. Paris, Librairie Polytechnique Ch. Béranger, éditeur.

It is this double result that will follow from a proper application of the Audouin System. The experiments made at Montjean in 1897, under conditions quite unfavorable, have nevertheless demonstrated that the creation of a channel under conditions that have been described above has been easily and rapidly realized. A certificate of the Foreman of the Society of Miners and Quarrymen of Montjean gives testimony from a practical point of view. The profiles drawn up by M. Audouin establish it equally. But as these facts have lacked official sanction in consequence of an absence of control, the Society of Amelioration of the Navigability of Rivers, which has been created to make known and exploit the Audouin System, has thought that a new trial, surrounded this time with all desirable guarantees, would establish, in an indisputable manner, the advantages claimed for this system. It is to carry out these views and in accord with the Service des Ponts et Chaussées the present project has been drawn up.

The locality has been selected, by common agreement, in the Loire, on the left bank a little above the mouth of the Maine. The works will commence a little below B. M. 558. The bank presents at this point a pool with a curvature sufficiently great to retain the channel constantly along it with a good depth of water. The dam will continue the curve of the bank across a bar through which is to be excavated the channel, and will be directed towards the following pool located at the downstream end of the Ile aux Dames.

The case is one which Engineer-in-Chief Girardon calls "a bad crossing;" for in plan the two pools overlap and the passage from one to the other (when it is possible) is made actually in following a direction almost normal to that of the bed of the stream.

The dam, of which the location and general direction have been fixed in concert with the Engineers of the Service of the Loire, will have a total length of 500 meters. The first part, 250 meters in length, constitutes a rectification of the left bank which it prolongs into the enlarged bed at this point, and which it joins tangentially. It will be made of wattlings held by piles having 3.5 meters penetration, driven 1.8 meters apart, with small piles between with 1.5 meters penetration.

The second part will also be 250 meters in length. It will be formed of piles of .25 m. average diameter, 7 to 7.5 meters in length, 1.8 meters apart, and will be driven so that their heads will have a uniform height of 2 meters above low water. They will have a penetration of from 4.5 to 5 meters; they will be united at their tops by a double course of waling. They will also be connected by a lower waling piece, held on by hoops, 2 meters below the upper waling. It will be placed under water. Each element will be 5.7 meters in length in order to be supported by four

consecutive piles. These waling pieces support the guides to receive and guide the vanes.

In order to make provision for the inevitable irregularities in driving piles, these guides, spaced .9 m. apart, will be placed between adjoining piles and will descend to the bottom or near it. They will receive the vanes, which will themselves be made in two parts, one fixed, the other movable, both being .8 m. in breadth. The fixed vane, 2.5 meters long, placed in the first guide, will be held at a fixed height by means of iron hooks fixed in its upper part. It will not be moved and will be withdrawn only when a flood is of sufficient magnitude to require removal of the dam in order to bring no obstacle to the free escape of the water.

The movable part, 1.6 meters in height, will move in other guides superposed on the first, and arranged so that the posterior face may move along the anterior face of the fixed vane. A rod, attached at the middle, permits the movable vane to descend as scour below is produced in order to preserve under it a sheet of water whose momentum continues to scour the bottom and to transport the soil to the rear, as has been explained in the memoirs of Captain Audouin. For this first trial the vanes, both fixed and movable, have been designed in wood. Later, for extended operations, they may be made of sheet iron.

The placing and maneuvering of both kinds of vanes will ordinarily be done by means of boasts moored in rear of the line of piles. The material carried by the Loire is composed almost solely of sand which travels along the bottom and enters into suspension only in the larger floods; the choking up of the guides, rendering maneuvers difficult or impossible, is therefore not to be feared. It is to be noted that these maneuvers will always be very easy from the small size of the vanes; if by chance they can not be made by hand, the normal manner, they can always be made by means of levers or windlass supported on the upper wales.

As already stated, the total removal of the vanes is only necessary in high floods when their presence in the major bed would form an obstacle likely to cause dangerous perturbations. The rest of the time they should remain in place until the desired channel is obtained and fixed in position.

It is recognized, of course, that one of the results of the establishment of the system considered will consist in the creation behind the vanes of a bar of which the height will grow successively up to a variable figure, in each case depending on local circumstances.

This bar should be protected and fixed progressively by the means ordinarily in use—spurs, sunken mattresses, plantations, etc. As it follows very closely the form of the dam and the latter determines the trace of the channel created, it is seen that it will constitute in some sort the bank of

the channel thus obtained, and, once properly fixed in position, it will continue to assure its direction and regimen when the dam is removed to be utilized elsewhere.

When the stream is in flood and the dam is submerged, it will not prove a danger to navigation, for the piles will serve to carry buoys which will mark their location and indicate to boatmen if navigation is still possible.

It is to be remarked that in this system, by utilizing the mean stage, the channel will be scoured out in a relatively short time; it will then be fixed in position. On the contrary, by the employment of submerged spurs, it will be only after a considerable time that the channel becomes useful, even if the depths desired are realized. In the former the realization is certain and, so to speak, immediate.

We may be permitted to emphasize the fact that the trial now in view has not for its immediate object to transform into a good crossing all the bar existing downstream of B. M. 558. The resources at our disposal do not permit undertaking this work in its whole extent. What we seek, especially, is to demonstrate that the system possesses the merits claimed and that its use at difficult localities furnishes the solution that other systems can not supply, at least with the same rapidity and security.

The estimated expense is 22,000 francs. We should ask the help of the state in order to make this trial, which interests to so high a degree all the country traversed by the Loire, an exhaustive one. We do not doubt but that it would be granted, as was done for the more important trials which are now in course of execution between the mouth of the Maine and Chalonnes.

Angers, February 9, 1905.

O. CHEMIN,

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Sketch of a New Method of Improving Rivers With Erodible Bottoms

BY

L. AUDOUIN
Captain of Artillery

Sketch of a New Method of Improving Rivers With Erodible Bottoms.

EXPLANATION OF PRINCIPLES:

We will take as the basis of our description the Loire between Nantes and the Maine.

The end to be attained is to assure the existence of a continuous channel in which is maintained, even during the periods of lowest water, a depth of water sufficient for navigation.

Considering that the discharge of the Loire at low water is only 120 to 150 cubic meters between Angers and Nantes, while the breadth of the river varies from 350 to 550 meters and more, it is evident that the channel can have a sufficient depth of water only on the condition that a species of minor bed of restricted width is formed.

To obtain this minor bed, we employ different methods, according as the river separates into several branches or, on the contrary, flows in a single bed. Where the river separates into several branches, we choose one of them in which to direct the channel and we regulate the entrance to this branch so as to concentrate therein the volume of water necessary to the existence of a good channel, while directing the sand towards the other branches. Where the river has only a single branch of considerable width we cause the formation of the minor bed by the execution of suitable works.

UTILIZATION OF THE FORCE OF THE CURRENT.

The current itself will be employed to dig its channel. The force thus brought in play was studied many years ago by M. Fargue, whose experiments lead to conclusions which may be summarized as follows:

"Every resisting surface struck more or less obliquely by the current becomes a center of concentration of momentum, and, if the bottom is erodible, also of scour. It, therefore, follows in a winding river that the channel will always be excavated along the concave bank.

"But the form of this bank is not immaterial; it must present a regular curve without abrupt change, and the succession of curves must be properly adapted to the width of the bed and the velocity of the current. At the points of inflection of the current are always found corresponding shoals which may be made to disappear by contracting the bed at these points."

These principles are evidently applicable to the Loire, the bottom of which is as erodible as possible, since it is formed of a very fine sand. If, therefore, the banks were regulated, following regular and progressive curves adapted to the case in hand, the channel would be excavated along the concave banks, and would always form at these points a depth of water sufficient for navigation. But shoals would occur at the points of inflection and the depth of water on these shoals resulting from the forming of the sand bars would be insufficient for navigation during the low water unless a contraction of the bed was effected at the points of inflection.

These contractions of the bed, on the one hand, have the advantage of removing, at the point considered, the obstacle which the bar opposes to navigation, but on the other, they present very grave objections. They result always in a lowering of the low-water plane, and consequently aggravate the difficulties of navigation on the bars higher up the river. They have in fact only suppressed an obstacle at one point, and caused it to reappear in an aggravated form a little higher up. Moreover, on the Loire the contraction of the bed has presented particular objections because the violence of the floods in this river, already so terrible, would be rendered still more dangerous.

The regulation of the banks is thus incapable of producing a complete improvement of the conditions of navigability of a river. But this regulation of the banks has nevertheless the advantage of assuring a permanent improvement by giving to the thalweg a direction more or less constant passing from concave bank to concave bank, and a depth which is insufficient only on the bars, and only during the period of low water. To complete this improvement, it would, therefore, be sufficient to find a means of creating, during the period of low water, an artificial channel through the bars.

In order that this requisite may be satisfied it is necessary and sufficient that the stream be permitted to dig through the bar, fairly rapidly, a channel of suitable depth in order that navigation may be always possible; it is also necessary that the creation of this channel shall

not result in material modification of the channel above and below, and does not sensibly change the level of the water.

OBLIQUE DAM.

Let us see how these conditions may be satisfied. Consider a winding portion of the Loire represented in Fig. 1, and suppose that the banks have been regulated as described above; the portions *ab*, *cd* are laid out in regular curves, and deep basins, or pools, are naturally produced extending from *ab* and from *cd*. It is a question of connecting these two pools through the bar in order to form a continuous channel. Place at BE an oblique resisting wall; its obliquity will produce a center of scour. But at the same time it contracts the section of flow, and the velocity will increase. This action being added to the first, scour will take place along BE at a rate increasing with the obliquity and length given to the dam. It will always be possible to choose the direction and length of this dam so as to obtain the necessary scour in the time desired.

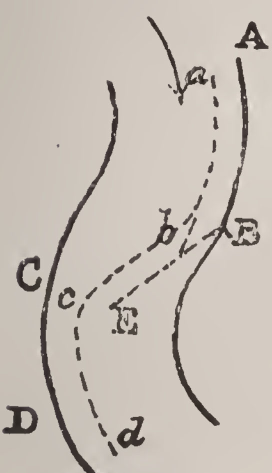

Fig. 1.

DAM WITH SUSPENDED GATES.

Let us see now how this scour will be effected and what will become of the sand carried along in the water.

It is known that sand held in suspension by a current drifts generally along the bottom of the river. If particles made from lemon are put in suspension they rest in layers, decreasing in density from the bottom to the surface of the water.

Therefore if, in place of making the wall BE a dam resting on the bottom, it is made with gates held a small distance above the bottom, there will be established under the dam a very strong current which will produce a rapid scour, carrying the sand behind the dam. If this bottom current is reduced to a depth quite small as compared to the total depth of water it will spread very quickly in the mass of calm water behind the dam, and the sand will be deposited. We might at our pleasure cause a deposit of the sand at a greater or less distance by increasing or diminishing the height of the passage left for the current under the gates.

As to the phenomenon of the concentration of momentum caused by the oblique dam, it will make itself felt in a zone more or less wide along the dam, there will result a scour along the bottom, and the

sand put in motion, rolling along the bottom, will fall in the deep excavation made under the dam, and it will pass in its turn behind the dam.

Thus the great proportion of the suspended sand will finally be deposited behind the dam, and will form a strand exactly in front of the convex bank, which is its natural place, from which the current will have no tendency to dislodge it, even in high water, when the gates of the dam will be removed, for the dam has been placed exactly at the point where the force of scour of the current is no longer sufficient to cause motion of the sand.

A very small quantity of the sand will be carried parallel to the dam; it will be deposited at the end of the dam in the zone outside the influence of the current and it will flow gradually into the pool *cd*, which will not be appreciably modified.

All these phenomena have been verified in an actual experiment (rather imperfect, however) carried out on the Loire in July, 1897, when the water was only $\frac{8}{10}$ of a meter above the low-water stage. The scour caused by the passage of the current under a slightly elevated gate caused rapidly in a few days an increase of depth of approximately one meter. As to the zone in which the concentration of momentum made itself felt, it reached a breadth of 30 to 40 meters, and the profile through it showed a regularity similar to that of an artificial canal.

By operating when the river was at the two-meter stage, the scour would be deeper, and the breadth of the scoured zone would be somewhat increased.

It is important to note that this scoured zone is quite narrow, and this is a fortunate circumstance, because the bar is not thus entirely removed; it is simply crossed by a narrow deep channel similar to the dredged channels recommended by M. Pasqueau, Inspector General of Roads and Bridges, for the work on the Garonne. These channels do not much modify the wetted perimeter of the river during low water, and they have consequently the advantage of giving more depth without causing a lowering of the plane of low water.

Thus, when the natural banks present a direction which resembles the normal direction (or trace) indicated by M. Fargue, it would be possible by simple and inexpensive works to give regular and progressive curves to the concave banks. Consequently, a continuous channel, always navigable, will be obtained by regulating the concave banks and by placing temporarily near points of inflection an oblique movable dam with suspended gates possible of regulation.

This method will have, over those actually in use, the advantage of not causing the permanent removal of the bars; it will dig in them only a narrow deep channel, modifying but little the wetted perimeter, and consequently not disturbing the condition of the river above, while giving at the point improved a depth of water greater than by any other method.

It will have at the same time the advantage of being more economical than other methods.

But it will not always happen that the plan of the natural banks allows us to give to the concave banks a regular curve sufficient to cause a scour giving a channel sufficiently deep. The experiments of M. Fargue have shown that in this case the channel indeed has a tendency to form along the concave bank; but is not maintained there in as regular a manner, and it has not a sufficient depth. These objections might be remedied by the employment of spurs attached to the convex bank. These spurs result in controlling the windings of the channel, and maintaining it along the concave bank; at the same time they retain the sand, causing a rise in the bottom along the convex bank, and consequently contract the section of flow: whence an increase in velocity and in the scouring force, which can be exercised only in the unprotected zone, causes the desired scour along the concave bank.

We see by the addition of these spurs that the principles proposed by M. Fargue become of a more general application, and we can always have along the concave bank the necessary depth of water. We may then make the channel across from one bank to the other, assuring the passage over the bar by the aid of a dam with suspended and regulated gates.

Such are the principles on which depend the works which we propose to use in localities where the river has only one channel.

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CHOICE OF NAVIGABLE CHANNEL.

The choice of the channel which must be reserved for navigation will be determined by considerations of two kinds: first, it is necessary that the breadth and configuration of this channel be well adapted to the maintenance of a good channel; in the second place it is necessary that the entrance of this channel be oriented and arranged so that the thalweg naturally directs itself to it in high water as well as in low water.

As to the first class of considerations, experience shows that narrow

channels whose width is in the neighborhood of a hundred meters and rather uniform, are those in which the channel is best maintained. To obtain, in such branches, a channel which will always be good, a few works of regulation on the banks to assure the regularity of the curves and uniformity of width will be sufficient.

To realize the conditions indicated by the second class of considerations, it might be necessary to make at the entrance to the navigable arm and above, rather considerable regulation works on the banks in order to insure, in all cases, the direction of the thalweg toward the entrance or the arm or branch chosen for improvement.

The advantages of utilizing narrow arms are sufficiently important to justify the execution of very considerable regulation works on the banks; for this utilizing of narrow arms will permit the establishment of transverse dams which may serve at the same time as ground sills for the regulation of the longitudinal profile, and as reservoir dams for raising the level of the water and for the creation of hydraulic motive power.

REGULATION OF BANKS.

The dam with suspended gates may be employed for the execution of regulating works on the banks under the conditions which will be indicated further on. It seems that the employment of this system of dams should procure the advantage ot promptly reclaiming certain portions of land cut off from the bed by regulation. This rapid reclamation might become for the state a source of considerable profit if care is taken, as was done before the execution of the works on the Maritime Seine, to have decided, by law, that the land thus reclaimed shall be the property of the state and not of the riparian inhabitants.

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GENERAL ORDER OF EXECUTION OF THE WORKS.

In order that the results of the employment of the proposed system may be appreciated, a complete scheme of the order of execution of the works must be presented.

First of all the banks must be regulated, following a reasonable plan: on the one hand, the attempt must be made to give to the concave banks the progressive form recognized as most favorable, and on the other care must be taken not to diverge so far from the natural forms of the bed as to diminish the importance of the works to be executed.

The work of bank regulation consists in replacing an irregular concave bank with an artificial bank of gradual curvature placed most often in front of the former bank.

This artificial bank is formed by a dam with suspended gates which will cause a rapid filling in of the portion cut off from the river bed. As soon as this filling in has attained a sufficient height the dam will be moved and the new bank will be covered with riprap.

This filling in offers important advantages. It furnishes a means of getting rid of sand put in motion by works of regulation, and which will thus be definitely thrown outside of the river bed. Moreover, if this filling can be raised to a height approximating that of the banks it will give a considerable extent of land which may be again put under cultivation and will have an important value.

It seems that this filling may be obtained rapidly by the employment of the dam with suspended gates, since the presence of this oblique dam causes the sand, which the scouring force carries forward, to pass immediately behind the dam. In whatever way this phenomenon may be produced, there is necessarily a difference of level on the two faces of the dam; therefore the water passing under the gates must find a sufficient opening for its discharge. It will not be necessary to raise the gates along the entire length of the dam: on the contrary, it will be necessary at certain points to lower the gates to the bottom, with their tops below the water level so that the water may return to the river, but not along the bottom where it might carry sand.

The arrangement of the dam will, therefore, be made along the following lines: starting at the upstream end, a section of fifty meters, in which the gates touch the bottom while their tops are above the level of the water: then fifty meters, in which the gates are raised above the bottom while their top is above the level of the water; finally, one hundred meters, in which the gates touch the bottom while their top is lowered below the water level. And so on in succession in sections of two hundred meters.

As the gates may be regulated, these arrangements might be alternated, and after a certain time the one hundred final meters of length might have the same arrangement as had formerly the first one hundred meters of length and reciprocately. In this manner scour would take place in front of the entire length of the dam, and the filling behind it would be effected readily.

With what speed will this filling take place? It is difficult to prognosticate in advance. The reclamations effected hitherto on other rivers like the Rhine can give only insufficient data, for in all

these works open sluices for the passage of the sand are required to be left in the artificial banks. The presence of the dam with suspended gates will perceptibly accelerate the movement of the sand. It might be foreseen that after one whole year or perhaps two years, the filling will have attained such a height that the dam may be replaced by riprap. It will then be necessary to employ the usual methods to continue progressively the filling at this portion of the bank until it reaches the height of the neighboring natural banks.

Where the concavity of the bank is insufficient, the regulation is completed by the use of spurs attached to the convex bank.

This first work will be completed as soon as possible, before the great floods of winter, because it is during the flood season that the filling may be pushed to the greatest height possible.

This first regulation will result in a localization, more or less regular, of the sand banks in the neighborhood of the convex portion of the banks; it will cause the existence of deep and regular pools along the concave banks where the current will be concentrated, but it will allow the sand bars at the points of inflection to continue.

Dams with suspended gates will then be put in place to force the channel to pass from one bank to the other through a narrow channel hollowed out through the sand bars, or to effect the separation of the current at the entrance of the false channels. Traced so as to continue the concave curve where the bank ceases to have sufficient curvature they will result in conducting through the sand bar a deep and narrow channel, and at the same time they will cause the elevation and regulation of the sand bars situated in front of the convexities. The gates will be put in place at the end of the high winter floods, at the beginning of the mean water stages, which M. Jacquet has called the regulating stage, and they will remain in place during the period of low water. They will be taken away in the autumn before high water in order to leave during the winter a free flow for the flood waters.

In order to leave a free passage both for ice cakes and other floating bodies, the pile dams may be arranged with as large openings as will seem necessary. The floating supports may be taken away when desired.

After taking away the gates the current will preserve sensibly the same direction, since we have taken care to make the thalweg during low water coincide with mean direction of the current during high water. Therefore no sensible change in the position of the sand bars will take place; there can be only a slight displacement of sand, since

the principal force of scour will make itself felt in the concave curves which will have been entirely protected against erosion. The sand bars will receive a part of the sand in suspension and a partial filling in the channel will be produced, which will be easy to get rid of the following spring by replacing the gates in front of the piles which have been left in place, or in front of the floating supports which have been put back in their place.

Thus even during high water the thalweg will preserve a direction which is almost permanent, and navigation may be continued without change. But this permanence in the direction of the thalweg must have on the longitudinal profile an influence which must be examined. In the portions where the river has only one branch, the sand bars are scoured away only on account of the presence of the dam; it will, therefore, be possible to arrest the scour at these points within any desired limit. Moreover, after the removal of the gates a partial filling will always take place each winter. Consequently there is no fear that the bed will be eroded in a progressive manner to an exaggerated depth.

In localities where the river has several arms, and where the current is concentrated in a single narrow arm, the bottom will be constantly subjected to the scouring force of the current, and the bed will be hollowed out in a progressive manner. It will probably become necessary to limit this deepening by the use of ground sills. But as these little arms will have a breadth of only one hundred to one hundred fifty meters the establishment of the ground sill will be less costly than would be the case if it were necessary to use it across the entire river over a breadth of four hundred to five hundred meters. It will even be advantageous to transform these ground sills into reservoir dams which will permit the level of the low-water plane to be raised, and will furnish a motive power more or less considerable, depending on the discharge and the fall. But this latter is a complement which is not necessary, at least in the beginning, for the establishment of the navigable channel.

At the entrance to the small arms the submerged separation dams will be established only after the deepening in front of the entrance has been effected. We should content ourselves at first with the construction of a dam with suspended gates at the head of the island. If sand enters the small arms it will not be deposited if their width and curves are regulated.

It is important to know that our bank regulation works apply to natural banks, and when we substitute for the natural bank an arti-

ficial work, this work is always raised to the mean level of the banks; that is to say, from three meters to three and a half meters above the low-water stage. This is an essential condition in order to obtain the anticipated scouring effects; for it is only at the time of mean discharges that the channel can be regulated in a durable manner, as has said M. Jacquet in the report already quoted.

On the Loire when the water falls to one meter and a half above the low-water stage the velocity of the current is scarcely one meter, and the scouring force is no longer very considerable.

It is during the two to three meter stages of water, of which the duration is quite a long time, that the scouring effects intended to direct the channel must be produced.

Other reasons, moreover, lead us to condemn low works which will be submerged for too long a time. As soon as an oblique wall struck by a current is submerged it necessarily ceases to be the cause of a scour.

This fact was observed very clearly on the Loire in 1897. Above Ingrandes the right bank between stations 87 and 88 is markedly concave, and there is ordinarily at this point a deep pool. Now, during the summer of 1897 there existed there a very high, firm sand bar. What could be the cause of this anomaly? Its causes were as follows: during the winter of 1896 and 1897 the Loire had several very great floods (the levee on the left bank between Montjean and Saint Florent was carried away). During these successive floods the water rose more than four meters and the water, passing above the natural bank, was thrown directly against the railway bank at Orleans. There was thus produced a concentration of motion and scour; so the little ditch which follows the railroad was deeply hollowed out, while the natural bank between stations 87 and 88 formed only an obstacle to the flow of the bottom waters and consequently caused a deposit of sand.

The theoretical explanation of this phenomenon is apparently quite simple. A wall struck obliquely by a current becomes a center of scour only on the condition that this current is intercepted in its upper layers and up to the surface. In this case, in fact, the exposed wall receives on its upstream face a pressure exceeding the hydrostatic pressure by the quantity $\frac{V^2}{2g}$. There results from this a difference of level: the surface of the water is lifted along the wall by a height corresponding to $\frac{V^2}{2g}$. This difference of level produces an increase of slope between the points struck and the neighboring points, and hence an increase in velocity. It is this increase in velocity added

to the increase of pressure which produces the scour on the bottom. But if the wall exposed to pressure does not extend to the surface the difference of level is much less, because the surface layers spread out immediately in the neighborhood; therefore the increase in velocity is produced specially at the surface, and is almost insensible in the lower layers. If, moreover, the exposed wall reaching to the bottom of the bed has a direction such that the liquid filaments at the bottom have their flow opposed and their velocity diminished, there will be a tendency to deposit.

Whence we must conclude that the banks which we wish to make centers of scour must be rarely submerged, and especially must we avoid placing on the bottom of the bed submersible works whose direction is almost perpendicular to the direction of the current in high water because these submersible works will become, in winter, centers of deposits which the summer waters will not succeed in removing.

There is still another advantage in regulating natural banks in that they are thus protected against the destructive effects of the current; consequently the transportation of sand in the river will be diminished, and the property of riparian owners will cease to be exposed to the encroachments of the river.

To sum up, the method proposed for the improvement of rivers with erodible bottoms consists essentially in requiring regulation of the banks of the mean bed, completed by the construction of spurs attached to the convex bank. This improvement, though permanent, is only partial and would be insufficient in low water. The improvement is then completed by the construction of an artificial channel through the bars, but only during low water.

The means proposed to create this channel consist of a particular arrangement of gates on a plan oblique to the current. The oblique dam with suspended gates constructed on this association of ideas produces a double effect: on the one hand, it causes a rapid scour following a definite direction; on the other hand, it produces the separation of the current of the lower layers containing almost all the sand from the upper layers of the current which carry no sand. These two portions of the current take different directions, the lower layers carry the sand outside of the channel, while the upper layers, in more considerable volume, are concentrated in the direction of the channel which we wish to reserve for navigation.

This phenomenon may be utilized for the improvement of rivers in

several very different ways, and its application is not limited only to the improvement of the Loire.

The advantages which an application of this system would present in the case of the Loire appear to be as follows:

This system, as we have just seen, protects the banks against erosion by the current, since all the concave banks are covered with riprap. As a result, riparian properties will no longer be in danger of being carried away by the river, and in this there is a considerable gain to the public, since M. Krantz has been able to calculate that the volume of earth carried away each year by the Loire lies between 500,000 and 1,500,000 cubic meters.

In the second place, this system is adapted to obtaining great drafts of water. It is an assured fact that the greater the curvature of a concave bank the deeper will be the pool which lies along it. We may, therefore, choose the curvature which is adapted to the depth we wish to obtain, and may make the effort to give to the banks a trace or plan which resembles this curvature.

Moreover, for the passage of the current from one bank to the other it is possible, by varying the trace and length of the dam with suspended gates, to increase the depth of the channel.

It must, moreover, be noticed that great depths of water may be obtained without modifying the elevations of the general water levels of the river: for they are produced by accentuating the dissymmetry of longitudinal profile without sensible modification of the wetted perimeter, nor of the mean level of the bottom.

On the other hand, there is one condition which every system of river improvement must fulfil: it must be adapted to changes which experience may suggest, and must not create any irremediable conditions.

The new system which we propose appears to lend itself better than any other to successive corrections, since to remove a dam with suspended gates it is only necessary to pull up the piles and place them in another position.

As to the net cost, it appears it ought to be lower than methods hitherto employed, for, according to an approximate calculation, the total expense of the construction of a navigable channel between Angers and Nantes would amount, under this system, to only ten million francs.

Finally, this system permits the ultimate establishment of transverse dams with heads of water, and, consequently, the creation of motive power.

We have seen above that permanent passage of the current in certain narrow arms might lead to a progressive deepening of these arms. It might become necessary to limit this deepening by a bottom sill placed at the downstream end of the arm. It will, also, be advantageous to utilize the bottom sills as reservoir dams. This is an advantage upon which it is important to insist.

As we have already shown, these bottom sills will be necessary at first only in narrow arms the width of which will be only one hundred to one hundred fifty meters: consequently, the establishment of these bottom sills with reservoir dams will be easy, without requiring an extravagant expenditure. If, in fact, conditions of construction similar to those existing at the Poses Dam are admitted, that is to say, a net price of twelve thousand five hundred francs approximately to the meter, a dam one hundred to one hundred fifty meters long will cost from one million two hundred fifty thousand to two million francs. Now, at Poses the reservoir dam head is four meters. Each one of the transverse dams to be built on the Loire would have a head of only one to one and a half meters, and might consequently be constructed under more economical conditions. The minimum motive force to be anticipated at each dam is that which corresponds to the minimum discharge of the river at low-water stage, namely, one hundred twenty-five cubic meters per second. For a fall of one meter the corresponding theoretical force would be 1600 H. P. The value of the utilization of this force is sufficient to fully pay the interest on a capital of two million francs. The navigable channel would, therefore, result from this work without cost to the state. We have already noticed the advantage which the navigable channel must secure from the establishment of ground sills, viz: the stability of the longitudinal profile. The addition of reservoir dams will bring other advantages for navigation, by diminishing the current, and by permitting the plane of low water to be raised so that without having need to seek exaggerated deepening in the channel, we may have always a sufficient depth of water for navigation.

Finally, the creation of motive forces along the navigable channel communicating with the sea will cause in the valley of the Loire an industrial activity and marvelous prosperity.

The Control of Rivers With Unstable Beds, With Special Reference to the Loire

BY

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The Control of Rivers With Unstable Beds, With Special Reference to the Loire.

The improvement and development of internal navigation, which is the indispensable auxiliary of railroads and maritime navigation, is at present engaging public attention both in France and abroad more than ever before.

But if an agreement has been reached as to the utility of navigable waterways, opinions differ as to the means for securing them.

It is often a question of deciding which of three methods to take:

1. Improvement by Regularization;
2. Improvement by Canalization;
3. Construction of a Lateral Canal.

LATERAL CANAL OR RIVER IMPROVEMENT.

In a canal, the depth is fixed and traction is as easy in one direction as in the other. But, on the other hand, the cost of constructing a canal is generally very great, particularly if it is desired that the canal be capable of handling a large traffic, which necessitates locks of great size. Moreover, a lateral canal serves only one side of a stream. Hence, for economical reasons and in order to respect, as much as possible, the rights of people living along a river, a lateral canal should not be resorted to, except in a case where the regimen of the river, its condition of slope and flow in a given part of its course, such as the upper part of the valley, do not lend themselves to any other method of securing a navigable waterway.

M. Barlatier de Mas, Inspector-General, in his report to the First National Congress of Internal Navigation at Bordeaux, states as follows: "Logically, river improvement should precede the construction of canals, the latter having as their object the prolongation of the navigable waterway, in the higher part of the valleys, where the natural waterways can not be used (lateral canals), or to connect different river basins (summit-level canals)."

The first method of river improvement to consider is regularization. At the International Congress on Stream Utilization, in Paris in 1889,

M. Boulé, Chief Engineer, very properly stated: "In most cases, works of regularization are indispensable, for, before a river can be canalized, the course and banks must first be fixed."

PROJECTS FOR THE IMPROVEMENT OF THE LOIRE.

In view of the above, Parliament acted wisely in reference to the Loire improvements, when, in passing the National Utility Act of December, 1903, it ordered the immediate execution of certain projects for the improvement of navigation in the vicinity of Angers.

These works have just been completed and their effect is already quite noticeable. Some of these works consist of épis* similar to those which have been constructed on the Rhone, the others consist of *oblique dams with sluice-gates.*

The first system is well known, while the second, on the contrary, is quite new and, as it has given better results, a description of it would seem to be more proper.

OBLIQUE DAMS WITH SLUICE-GATES.

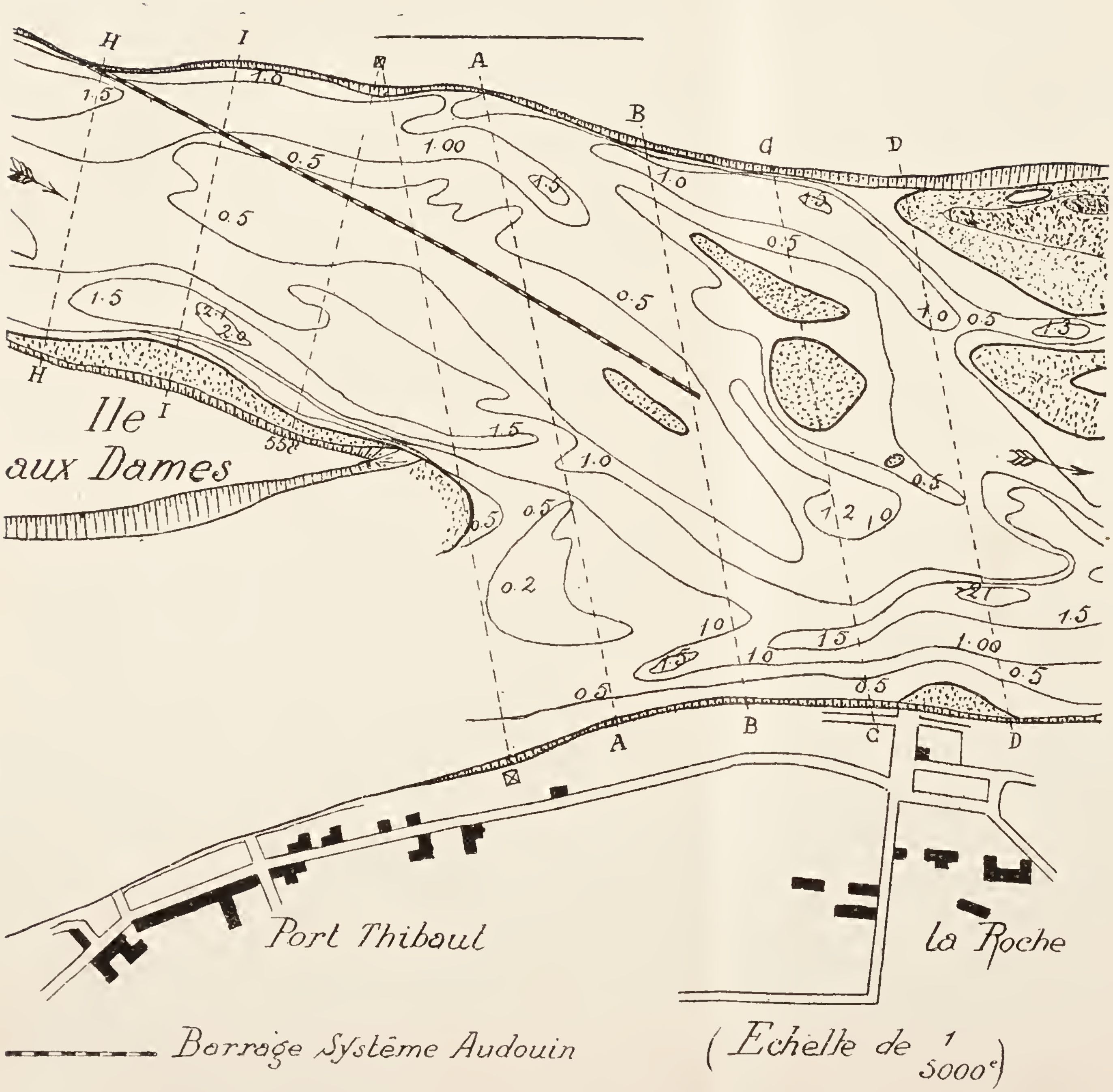
The system of oblique dams with sluice-gates depends on the fact, that in all streams with unstable beds, the movement of sand and gravel by the current is principally on or near the bottom. The object of the system is the regularization of the stream by an automatic decantation, in which the upper layers of the current are concentrated in the channel so as to deepen it by scour, while the lower layer, passing under the gates of the dam, carries the sediment beyond the channel.

It is well known that, according to the natural laws of the regimen of rivers with unstable beds, as established by M. Fargue, Inspector-General of Ponts et Chaussées, the channel always forms along the concave bank when this bank is regular and without sudden change of curvature and the succession of curves is properly suited to the size of the bed. In order to assure the constant formation of pools, the banks, and particularly the concave banks, must first be prepared by replacing the irregular natural banks with artificial banks of gradual curvature. When the position of the pools has once been established, it remains to deepen the channel on the bars that form naturally at points where the current changes direction, *i. e.*, where concavity changes to convexity.

This double result can be secured rapidly and economically by

*Low spur dikes.

Plan de sondage levé avant implantation de l'ouvrage
(Sondage exécuté les 19, 20, 21, 22 et 23 septembre 1905)



Plan dressé par l'Administration des Ponts et Chaussées (*Service spécial de la Loire*, 4e section);
M. Cuénot, ingénieur en chef; M. Philippe, ingénieur ordinaire).

Nota. — Les chiffres placés à côté des courbes de niveau indiquent les profondeurs *au-dessous* de l'étiage.
Les grèves s'élevant au-dessus de l'étiage sont indiquées par un sablé.

means of oblique dams with sluice-gates, as has just been demonstrated by the new works on the Loire about three kilometers above the junction of the Maine and near Port Thibaut. The project for these works was prepared by M. Chemin, Chief Engineer, and was approved by the Minister on the 26th of August, 1905.

CONDITIONS PREVIOUS TO COMPLETION OF IMPROVEMENT (PLATE I).

The dam is located on the left bank of the Loire, at the outlet of that arm of the river which is south of the Ile aux Dames. This arm, which begins at Ponts de Ce, has a mean width of 150 meters and receives the larger part of the low-water flow of the Loire; consequently it has, as a general rule, a fair channel. But, near the outlet, its width becomes excessive, and the left bank, which to within 200 meters of K. 558 is sufficiently concave to maintain a good channel, changes sharply at this point to convexity. For this reason, a bar formed in the middle of the bed, and, as can be seen by the chart of soundings taken on September 19 to 23, 1905 (Plate I), the crossing was very bad before the works of improvement were commenced. A pool extended along the left side of the stream near the bank, and on the right side, a pool existed along the lower part of the Ile aux Dames, the crossing from one to the other being made across stream and in depths that did not exceed one-half meter during the low-water stage.

DESCRIPTION OF THE WORKS.

The dam starts at the point H (Plate I) where the change of curvature of the left bank takes place. Its trace is a curve, which is a continuation of the concavity of the left bank, and it is directed towards the pool which is near the right bank of the river between the points K's 59 and 60. The annexed photograph (Fig. 1), taken from near the upstream end, shows the curved form of the dam. It has a total length of 450 meters and consists of two parts, as set forth by M. Chemin in his project:

"The first part, 250 meters in length, is a rectification of the left bank of the stream. It is tangent to the bank at the point where it joins it, and prolongs the bank into the widened stream bed."

The second part of the dam is 200 meters in length and is intended to cause the formation of a channel of sufficient depth across the bar at the point where the current changes direction.

Both parts of the dam are of similar construction. They consist of

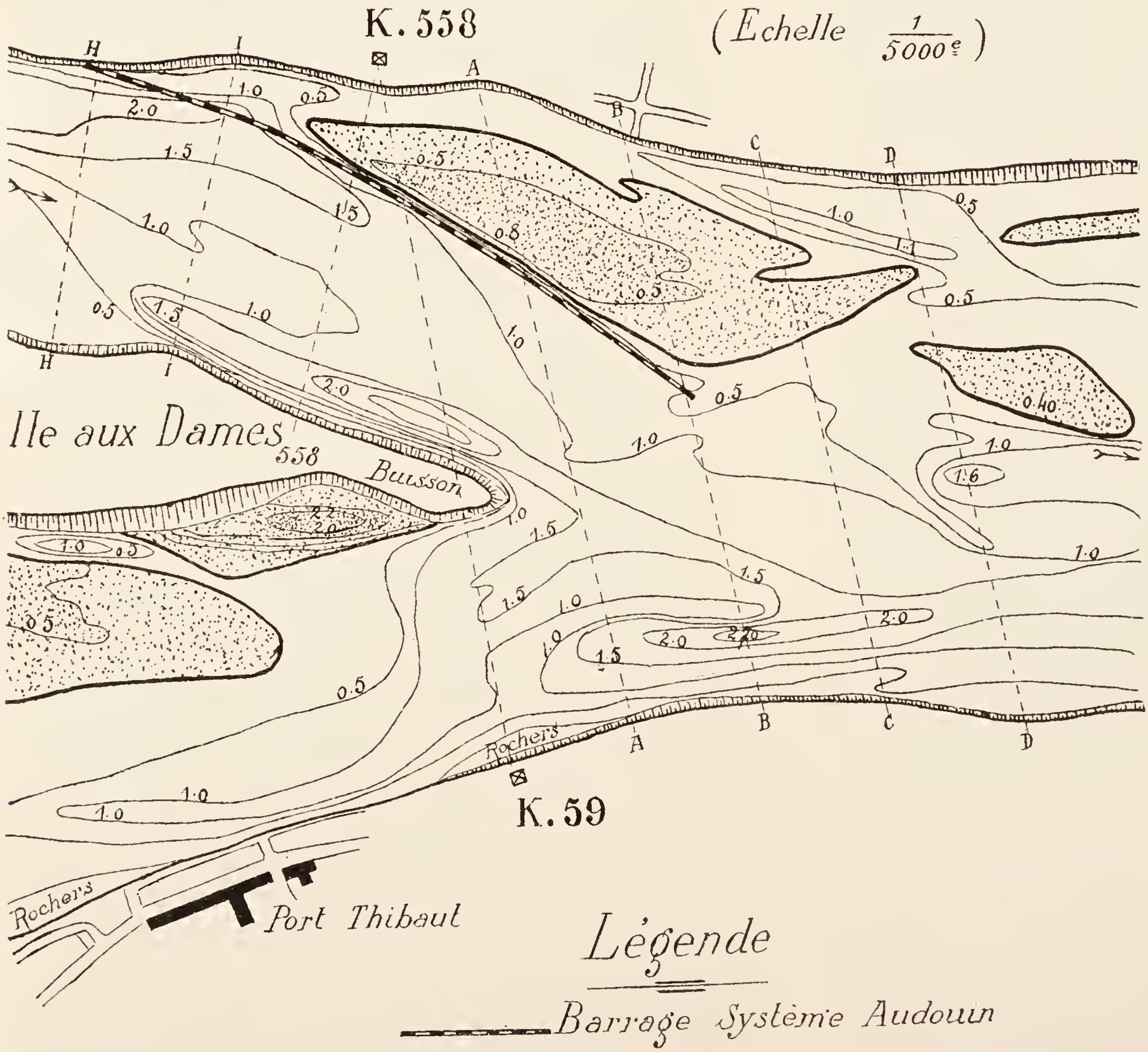
a single row of piles of 8 meters average length and 30 centimeters average diameter, spaced 2 meters and so driven that their tops are 2.25 meters above low-water mark. The tops of the piles are joined by two courses of waling pieces, 20 by 10 centimeters, bolted to them. A third row of waling pieces, which serves to hold the lower ends of the upright guides, consists of pieces 4.50 meters in length, each of which is fastened to three piles. As this third course was put in place when the stage of the water was 2 meters above the low-water stage, they could not be bolted to the piles as were the upper courses and were hence fastened to the piles by means of metal collars. This

Fig. 1. View of Entire Dam.

latter course was placed 2 meters below the upper courses, and before each piece was put in place there were fastened to it the four wooden guides which it was designed to hold. These guides, which are spaced 1 meter apart, were then fastened to the upper waling courses. They are for the purpose of guiding the wooden gates, which are 4 meters high, .90 m. wide and .02 m. thick, and provided with uprights, so that they may be raised or lowered easily by hand. Fig. 2 shows a man in the act of raising a gate by hand. The gates are held at the desired height above the bottom by means of loose bolts which are inserted in holes in the uprights and rest on the upper waling courses.

The gates of the first part of the dam were put in place on March

Plan de sondage levé trois mois après l'achèvement de l'ouvrage
(Du 14 au 16 août 1906)



Plan dressé par l'Administration des Ponts-et-Chaussées (*Service spécial de la Loire*, 4e section)

Nota. — Les chiffres placés à côté des courbes de niveau indiquent les profondeurs *au-dessous* de l'étiage, excepté ceux qui se trouvent dans les parties pointillées représentant les grèves ; ces derniers indiquent la hauteur au-dessus de l'étiage.

29, 1906, when the stage was 2.25 meters above low water, while those of the second part were put in place on May 16, 1906, the stage at that time being only 1 meter above low water.

RESULTS OF THE EXPERIMENT WITH OBLIQUE DAMS WITH SLUICE-GATES.

The results, as shown by the chart of soundings taken on August 14

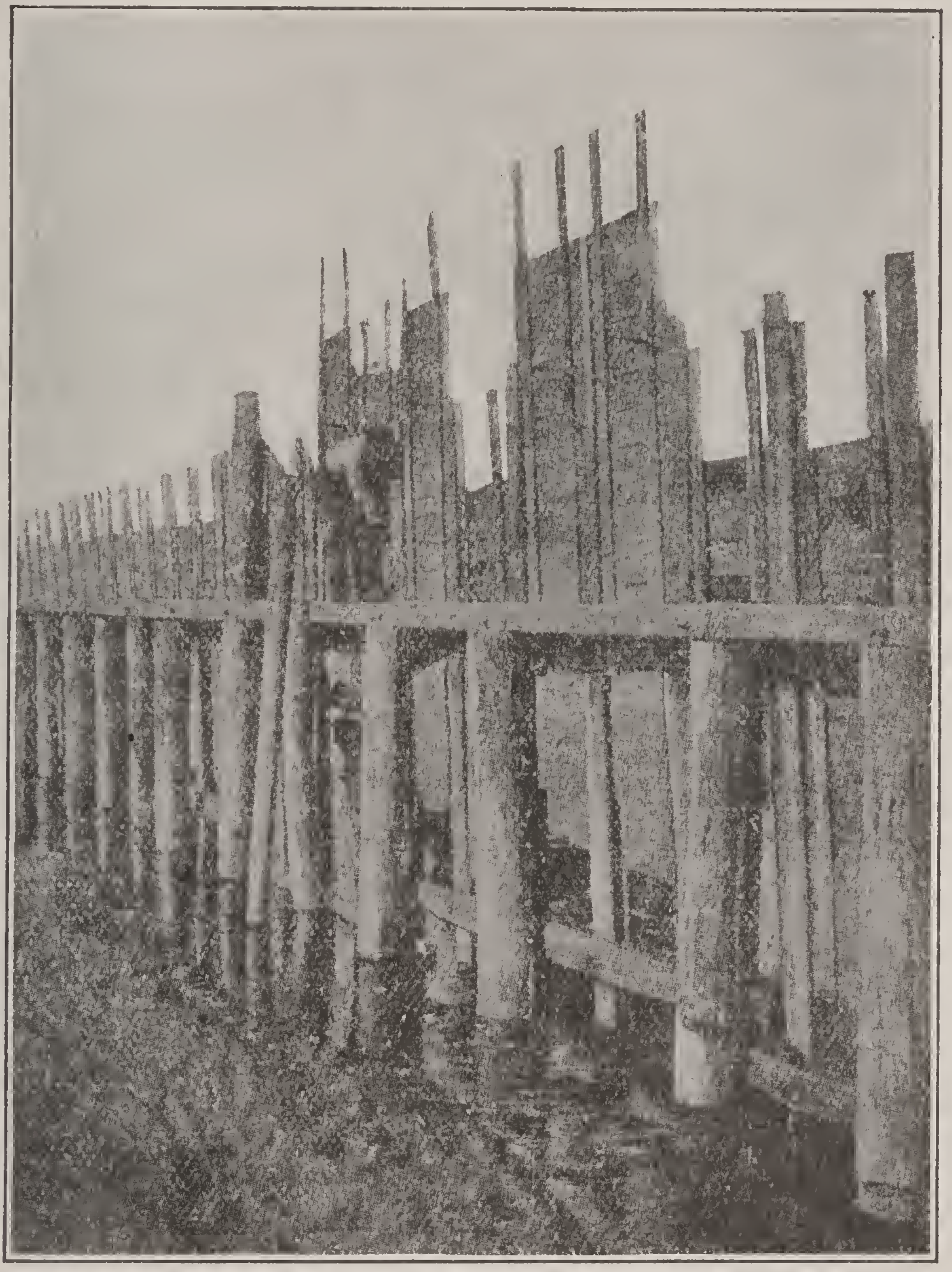


Fig. 2. Maneuvering the Gates.

to 16, 1906, three months after the completion of the work, are as follows (Plate II and Fig. 3): A channel, at least 60 meters wide, had already been scoured out along the first part of the dam, with the following depths at low water:

Cross-section 557 H (left bank), 2.20 meters.
Cross-section 557 I, 2.10 meters.
Cross-section 558, 1.60 meters.
Cross-section 558 (left bank); 59 (right bank), 1.40 meters.

A very large amount of sand had passed under the gates and had been deposited between the dam and the natural bank in a height of more than 1 meter.

Along the second part, which had been put in place two months after the first and in quite low water, the scour was not so great; nevertheless, a depth of 0.70 m. had already been attained in August, 1906. The channel was deviating from the dam in such a direction as to join the pool which existed along the Ile aux Dames and had a low-water depth of more than 1 meter.

During the winter of 1906-07, the gates were left in place, but raised as high as possible, and the dam sustained the test of high water and ice without damage.

The chart of soundings taken on June 19 and 20, 1907, shows that the channel follows the dam throughout its entire length, with a low-water depth of not less than 1.50 meters and that it is being extended downstream toward the pool on the right bank of the river between the points K. 59 and K. 60 (Plate III). The pool which formerly existed along the lower part of the Ile aux Dames has disappeared, as had been foreseen; since the dam prolonging the concave curvature of the left bank would necessarily retard the change of direction of the current. This was a secondary pool which it was advisable to dispose of. The flow is now concentrated in the middle of the bed, across the bar which formerly obstructed it and which in 1905 extended above low-water mark. The sand has been diverted to one side. The sand bank, which formed behind the dam in 1906, is extended downstream along the left bank, where it aids in limiting the channel below the dam and giving it a good direction.

It will be noticed that the effect of this dam is felt for 200 meters below its downstream end. For 150 meters the channel has a low-water depth of 1.50 meters and holds the direction which the dam gives to it, while for the remaining 50 meters, or the distance to the pool along the right bank, the depth as yet is only 1.30 meters below low-water mark.

RESULTS OF IMPROVEMENT WITH ÉPIS.

It is interesting to compare the results of this work with those of works of improvement by means of épis, which were constructed on the Loire below the confluence of the Maine. An examination of the official charts of soundings, on exhibition at the Exposition of Bordeaux, and which show conditions both before and after the construction of the works of improvement, would make evident that épis

Profils dressés par l'Administration des Ponts et Chaussées

Service spécial de la Loire
4e section

LÉGENDE

— — — Fond du fleuve avant implantation de l'ouvrage.

——— Fond du fleuve en août 1906, trois mois après l'achèvement de l'ouvrage.

Nota. — Les cotes indiquent la profondeur au-dessous de l'étiage, excepté celles qui sont précédées du signe + (derrière le barrage) ; ces dernières indiquent la hauteur au-dessus de l'étiage.

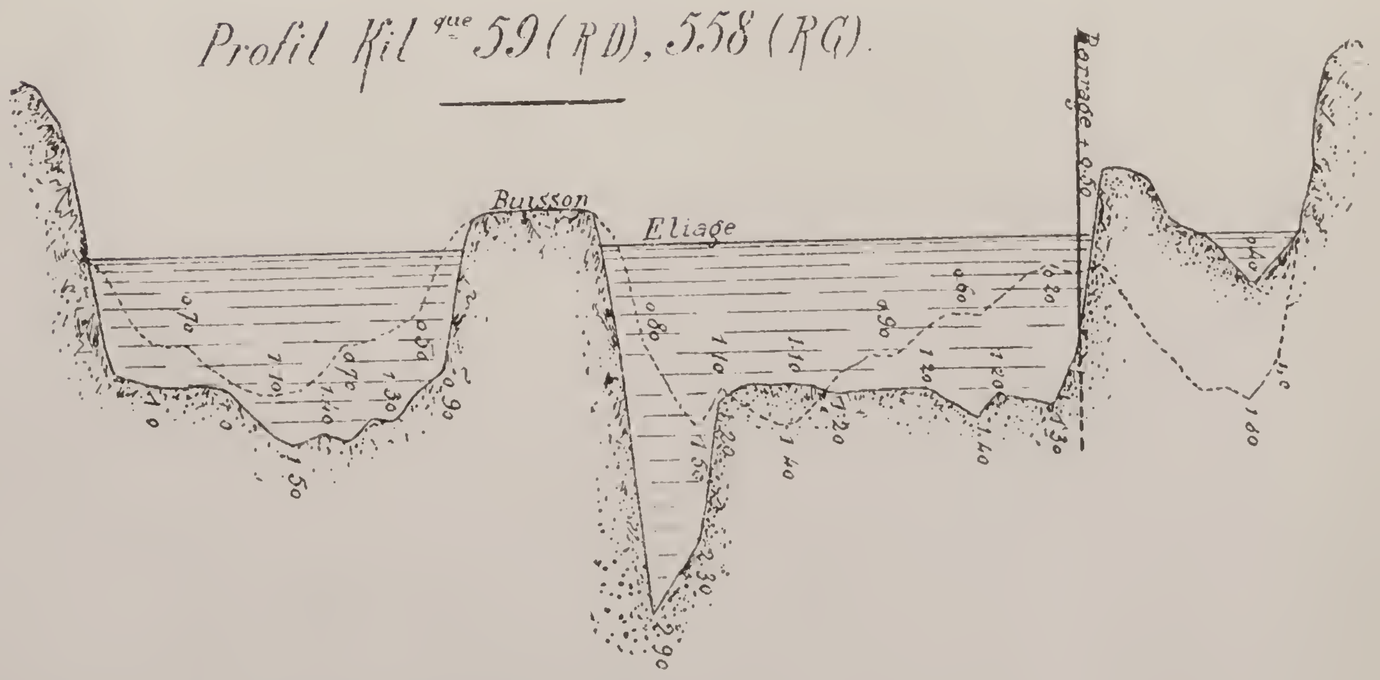


Fig. 3. — Profils en travers de l'ouvrage.

are not without value in certain ways and that a channel is being scoured out in places. But what is most important and must be most considered is the existence of a continuous channel and the minimum depth of water over all of the improved section of the river. Now, in the branch of Chalonnes, as shown by the charts of soundings, a number of crossings exist when the channel has a low-water depth of less than 0.50 m. Likewise, in the part between the Ile de Chalonnes and the Ile de Behuard, there are several bars on which the low-water depth does not equal 1 meter, though the works have been completed for three years and have had time to produce their effect. At least such was the case last April, which was the time when the data for the latest chart of soundings was secured. It is possible that this condition of affairs may have been improved upon since that time, due to the extensive dredging that it has been necessary to resort to. Dredging, however, will not secure a permanent channel and, as it must be often repeated, the cost of a channel by such means is great.

ADVANTAGE OF OBLIQUE DAMS WITH SLUICE-GATES.

One of the advantages of oblique dams with sluice-gates is that dredging is not required, since the effect of the dam itself is a sort of automatic dredging.

Moreover, the results, so far as the regularization of the banks is concerned, are more rapid than with any other method, and this is of the highest importance, not only for navigation, but also for agriculture.

"*The fixing of the banks,*" states M. de Mas in the report already quoted, "which is an essential part of works of regularization and which with us in this later system has generally preceded canalization, *assures the conservation and even the increase of national resources;* conservation in putting an end to the erosions which destroy valuable lands, and increase, in permitting the utilization of lands the cultivation of which had previously been impossible."

The oblique dam with sluice-gates not only regularizes and protects the banks, by substituting for the irregular natural bank one that is artificial and regular and less liable to erosion, but also causes the rapid filling up of the interval between the old bank and the new. Hence, in addition to protecting the property of riparian owners against the action of the current, it causes the stream to reform in a short time important areas which it had previously destroyed. There is, therefore, to use the expression of M. de Mas, an increase of national resources, sufficient to justify works of this character, even when the question of improving navigation is not considered.

As is well known, most of the works of regularization of rivers in Germany, as well as those on the Garonne, have been executed in the interest of agriculture as well as navigation. M. Robert, Chief Engineer, says on this subject in a report to the Eighth International Congress of Navigation in Paris in 1900:

"The works of regularization on the Garonne, undertaken in the interests of both agriculture and navigation, are for the purpose of concentrating all the flow, except at a time of inundation, in a single bed with fixed and regularly traced banks."

METHOD OF REGULARIZATION.

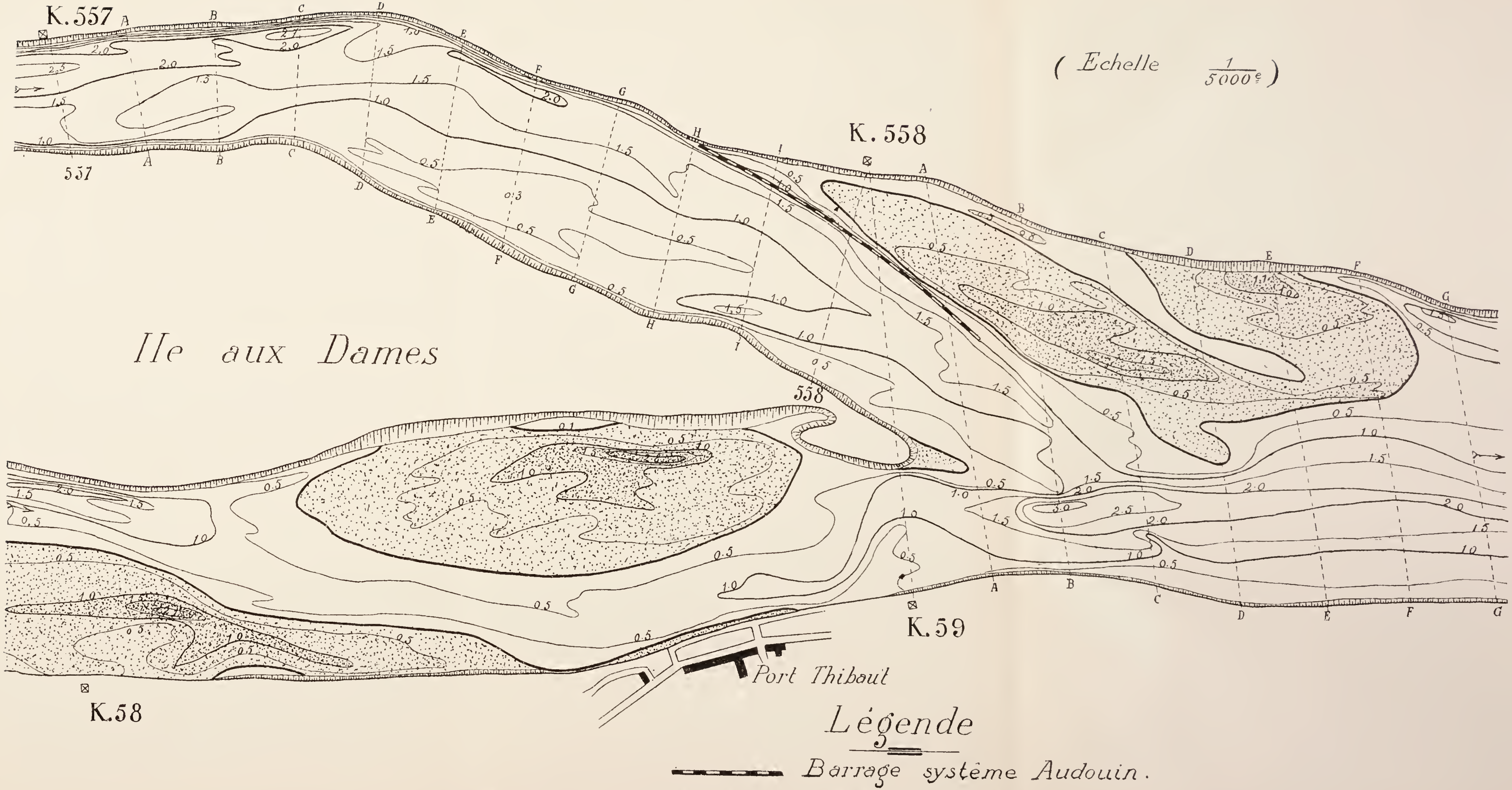
In order that works of regularization may be beneficial to agriculture they must be applied to the mean bed, that is, the area covered by water when the stream flows full to the banks, and not to the minor bed, which is the area occupied by the stream at the low-water stage. The low ground between the banks of the mean bed is covered by water the larger part of the year and only in rare instances is suitable for cultivation. Hence, the banks of the mean bed are those most suited for regularization and protection, in order to prevent erosion and to recover land. The banks of the mean bed of the Garonne are those to which the remarkable works of regularization of M. Fargue, Inspector-General, were applied. On the Rhone also, the work of regularization consisted first in the rectification and establishment of the mean bed by the use of longitudinal dikes. M. Jacquet, Inspector-General, who had charge of the works of improvement on the Rhone before M. Girardon, Chief Engineer, says on this subject in a report to the International Congress on Stream Utilization at Paris in 1889:

"Dikes should concentrate the water of stages that are sufficiently high to have an efficient action. The height adopted for the crown of the dikes on the Rhone was 2 meters above the low-water stage between Lyons and Isère, 2.50 meters between Isère and Ardèche and 3 meters between Ardèche and tidewater."

M. Jacquet has remarked that the action of the current upon the bed of a stream depends on its volume, and with a given volume, upon its duration, and further, that the state of the bed that is most permanent is due to mean volumes, sufficiently strong to act sensibly on the bottom and yet durable enough for this action to be efficient.

"Neither floods nor low-water flow," he states, "give to the bars and to the bed of the stream the forms and the relief that are noticed at the low-

Plan de sondage levé les 19 et 20 juin 1907



Plan dressé le 6 juillet 1907 par l'Administration des Ponts et Chaussées (*Service spécial de la Loire*, 4e section).

water stage. The effect produced by floods is modified by the lower stages which follow, and which determines the definite form that remains after each flood. These intermediate stages are the real regulators of the low-water bed."

Since the mean volumes of flow determine the shape of the minor bed, it is to the banks of the mean bed that works of regularization should be applied.

The works of M. Girardon on the Rhone are applied to the minor bed and the same is true of the épis which have just been placed on the Loire, between the confluence of the Maine and Chalonnes. The two types of works which have just been completed on the Loire differ, then, not only in construction, but also in the method of regularization; the works at Chalonnes being an example of one method, that of M. Girardon, while the recent works at Port Thibaut exemplify the method of M. Fargue. In the first, it is desired to fix a channel in the minor bed by means of low works, without regularization of the banks themselves, the channel crossing from side to side with many curves. In the second method, a concave or directing bank of the mean bed is regularized by means of a high work, and at the change of direction of the current a channel is formed, following the direction the current of the mean stage would take when directed by the regularized concave bank.

Experience seems to have demonstrated that the second method is preferable to the first both for navigation and for agriculture. It is confirmed by the opinion of such eminent engineers as M. de Timonoff and the members of the Mississippi River Commission, according to whom "no improvement of the minor bed should be attempted so long as the direction of the high-water flow is not established."*

COST.

The method of improvement, tried near Port Thibaut, is not only better for navigation and agriculture, but is also more economical. The section of the river which has been improved by means of these works and on which a good channel has been secured has in all a length of more than 2 kilometers. This result has been secured with an expenditure of about 30,000 francs. If, in order to determine the cost of this system of improvement, only the distance between the centers of the pools joined is taken into consideration, the cost would be 30,000 francs per kilometer. According to the project for the regularization of the Loire by means of épis the cost would be more than 100,000 francs per kilometer. Hence,

*Report to the Eighth International Congress of Navigation in Paris in 1900, page 180.

with the system of dams with sluice-gates, the cost would be less than one-third as great, and the Loire could be made navigable from Nantes to the confluence of the Maine for less than 3,000,000 francs. It should not be difficult to secure such a relatively small sum for so important a work. Parliament, after having appropriated 1,600,000 francs for works of improvement over a length of 12 kilometers, should not hesitate to appropriate a sum twice as large to make the Loire navigable over a length of 84 kilometers, from Angers to Nantes. The easiest way to secure this amount would seem to be that as the works are authorized the departments interested be requested to furnish one-half of the amount necessary, while the government furnishes the other half.

When the Loire has once been made navigable from Nantes to Angers, which is the most urgent, work of improvement could then be carried on upstream as far as Vienne and finally to Tours and Orleans.

STORAGE RESERVOIRS.

According to a report of M. Schwob to the National Congress of Navigation, the Loire could be made navigable as far up as Briare by means of storage reservoirs.

"In order to control and utilize the Loire as far as Briare," says M. Schwob, "there must be an increase of the low-water flow of 40 cubic meters per second. After the great floods of 1857, M. Comoy, Inspector-General, made a rapid study of storage reservoirs for storing a part of the water during floods. Sites for these reservoirs were selected and the cost of construction calculated. The cost of works storing six hundred million cubic meters of water was found to be sixty-five millions of francs. M. Comoy estimated that this cost would be largely compensated for by the security against floods that would thereafter be furnished to the inhabitants and property owners along the river. Nevertheless, the Imperial Government could not provide the requisite funds. At the present time conditions are much better. Due to the rapidity of telegraphic communication, the open storage reservoirs of M. Comoy could now be changed to closed reservoirs, which could be drawn on at the least change of stage.

"Therefore," continues M. Schwob, "they could be used:

"1. As sources of supply during low water, increasing the amount of flow from 70 to 80 cubic meters per second during the low-water period, which is double the amount necessary for purposes of navigation.

"2. As a source of motive power, permitting the establishment of industrial plants in the country surrounding Saint Etienne, Montluçon, Clermont, and as far as Bourges.

"3. Finally, since the amount of water stored would be much greater

than that required for purposes of navigation, part could be devoted to agricultural purposes after it had passed the turbines."*

Storage reservoirs alone are not sufficient to make the Loire navigable, but by acting as regulators in diminishing the ratio of the volumes of flow at high and low water stages they would improve the regimen of the stream and would permit works of regularization to have their best effects both in the lower part of the Loire and as far up as Orleans.†

COMPARATIVE COSTS OF REGULARIZATION AND A LATERAL CANAL.

Omitting the cost of storage reservoirs, which would be largely compensated for by the profit accruing to manufacturing establishments and agriculture, an expenditure of twelve millions of francs would make the Loire navigable from Nantes to Orleans.

According to an estimate made recently by the administration of Ponts et Chaussées, a lateral canal from Nantes to Orleans would cost about one hundred and ninety millions of francs. Such a sum, in the opinion of the Paris Chamber of Commerce, seems out of proportion to our resources.

Works of regularization will cost little and offer, as has been shown, the advantage of serving both navigation and agriculture.

ADVANTAGES OF CANALIZATION FOLLOWING REGULARIZATION.

The very important results which are procured at first by works of regularization may be completed later by canalization. An eminent engineer, who has a good knowledge of conditions on the Loire, M. Léchalas, Inspector-General of Ponts et Chaussées, has always maintained that the

*The Eighth International Congress of Navigation, which met in Paris in 1900, reached the following conclusion on the advantages of storage reservoirs:

"One of the means that are available for the improvement of the regimen and the navigability of rivers is the use of storage reservoirs for increase of the flow at low-water stages and also in certain cases to reduce the height of floods. Storage reservoirs have been used with success, and others are being planned, and this means, which has the additional advantage of being a source of power that can be made available through the achievements of science, is commended to the attention of engineers and governments."

†I had the honor of calling the attention of the General Council of Maine-et-Loire, during the session of August, 1906, to this important subject of storage reservoirs, and at the same time to the necessity of taking immediate measures to prevent sediment from the basin of the Allier being carried into that of the Loire. This was in accordance with a resolution adopted by the Twelfth Congress for the improvement of navigation on the Loire, and the General Council of Maine-et-Loire adopted a resolution on the subject.

Loire can be made a good navigable waterway by regularizing it at first and finally canalizing it by means of movable dams.

No better navigable waterway exists than a river canalized like the Seine, since its capacity for traffic is much greater than that of an ordinary canal. Another advantage of a canalized river is that motive power may be generated at the dams, which is available for towing boats and for industrial establishments along the river. The benefits arising from these hydro-electric installations, which are now being introduced everywhere, would tend to compensate for the cost of construction of the navigable waterway and would aid its operation.

I would add that, for the Rhone, which has been regularized, the best thing to do now is to canalize it, instead of constructing a lateral canal, which is under discussion.

Future development will be in the direction of the canalization of rivers, large locks being provided, which will permit the movement of fleets of boats, and boats of large tonnage, the power necessary for traction being generated at the dams.

But canalization supposes a previous regularization. It is eminently proper, then, to commence the improvement of the Loire by regularizing it and making it navigable at a small cost. Then, when once the boat traffic of the Loire has been restored, the depth can be gradually increased and the expenditures regulated as the growing needs of traffic demand.

E. Audouin.